

# Advanced Integration of Multi-Scale Mechanics and Welding Process Simulation in Weld Integrity Assessment

Y. Wang, W. Cheng, M. Liu, S. Babu<sup>1</sup>, D. Parks<sup>2</sup>, and S. Hao<sup>3</sup>  
Engineering Mechanics Corporation of Columbus, Columbus, OH

<sup>1</sup>Oak Ridge National Laboratory, Oak Ridge, TN

<sup>2</sup>Massachusetts Institute of Technology, Cambridge, MA

<sup>3</sup>Northwestern University, Evanston, IL

## Project Incentives

- The complex thermal cycles from welding usually produce a weld joint with microstructures and material properties different from those of the parent metal, and hence may not be optimum for the intended application.
- The thermal cycles also result in the build-up of residual stresses in the weldment. Furthermore, all welds contain some degree of imperfections.
- The reliable performance of these weld joints in various service environments can be the limiting factor for the safe operation and the service life of many industrial components.
- Accurate performance and reliability assessment of welded structures has been a major technical challenge.
- Welding process simulation has been under development in the U.S. and Europe. However, the practical application of this technology in the U.S. energy industry is limited.
- To a large extent, the European countries have taken a lead in developing both deterministic and probabilistic weld integrity procedures in the last two decades.
- Developing accurate and reliable weld integrity assessment procedures is critical to all industries where welding is a key fabrication technology. Today in the U.S., over 50% of the gross national products are associated with the production of welded products.

## Energy infrastructures and their welds have to survive very severe loads



- Incorrect welding procedure design and implementation can affect infrastructure integrity.
- Unreliable energy infrastructures can have negative impact on energy conservation and environmental protection.
- Weld integrity assessment procedures are needed to predict the weld behavior under variety of loading conditions.

## Improved welding technology and weld integrity predictions are needed to ensure energy supply at the minimum cost to the environment.

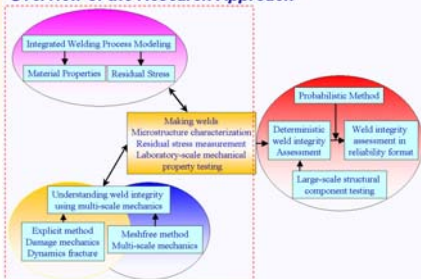


- Key energy infrastructures are being planned and constructed at sensitive environmental areas.
- New welding technology allows the use of ultrahigh-strength steel, thus reducing the steel consumption and the associated energy usage in steel production.
- Improved weld integrity assessment allows high integrity welds at the minimum cost of energy and environmental footprint.

## Project Concepts and Objectives

- The proposed approach is motivated by experimental observations that macro-scale response of a heterogeneous weld is intrinsically related to its micro-scale features.
- The goal of the project is to develop advanced integrated weld integrity-assessment procedures by integrating fracture mechanics and damage mechanics modeling with the latest welding process modeling techniques.
- This technology will then be implemented in a suite of computational tools that offer reliability-based weld integrity assessment procedures for welded joints and structures.
- The initial focus of the implementation will be on energy pipeline industries for the following reasons:
  - The steels used in the energy pipelines represent the latest and mostly highly engineered steel products produced by some of the most advanced steel making technology.
  - The welding processes in the construction of the energy pipelines reflect some of the most advanced welding technologies, applied in large scale and under difficult field environment.
  - The completed weld joints in energy pipelines are expected to survive under some of the most severe loading conditions. This service condition presents the greatest challenge in weld integrity assessment.

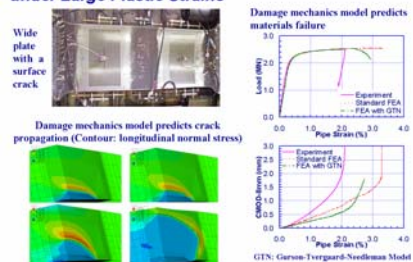
## Overview of the Research Approach



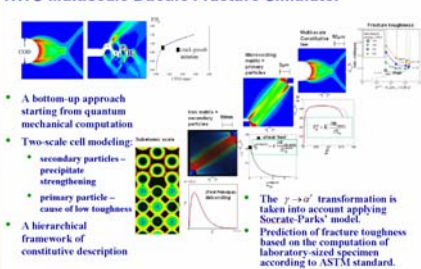
## Milestones of the Proposed Research Approach

- Develop welding process modeling techniques that are capable of predicting the weld microstructures and mechanical properties from the knowledge of welding process conditions.
  - model for weld metal thermodynamic predictions
  - microstructure-prediction algorithms for weld metals
  - weld metal toughness-prediction models
- Develop deterministic weld integrity assessment methodology by incorporating the results of the welding process modeling, micromechanics, and the latest fracture mechanics and damage mechanics analysis.
  - test method for measurement of materials resistance to failure under both elastic and plastic conditions
  - multi-scale mechanics approach for description of crack driving force relations for low and high applied strain conditions
- Expand the deterministic procedure to a reliability-based weld integrity assessment methodology that takes into account the natural variation of material properties in the welds.

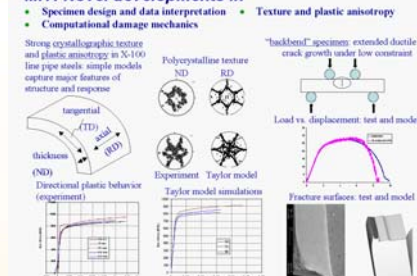
## Damage Mechanics Simulation of Weld Response under Large Plastic Strains



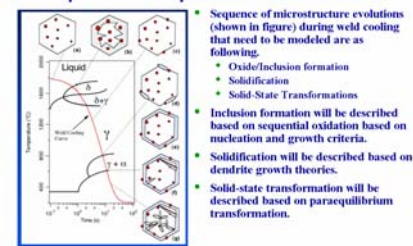
## NWU Multiscale Ductile Fracture Simulator



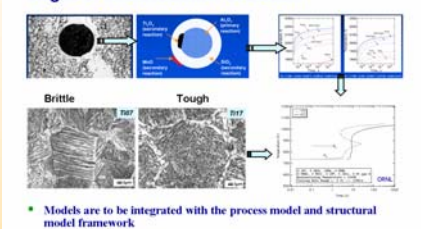
## MIT: Novel developments in



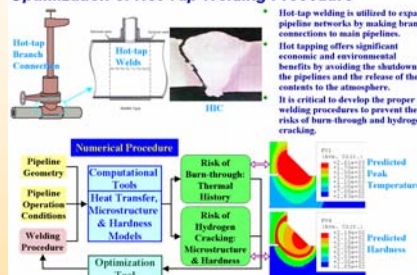
## Weld metal microstructure algorithm to be developed based on published works at ORNL



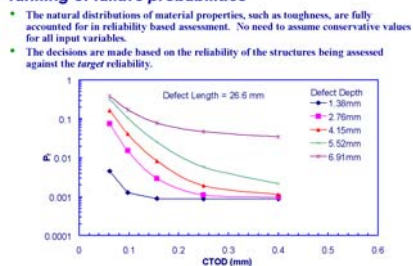
## Projected features of the models for different stages of microstructure evolution



## Optimization of Hot-Tap Welding Procedure



## Reliability-Based assessment provide quantitative ranking of failure probabilities



## Industrial Partners

- Pipeline Research Council International (PRCI) representing the following (selected) companies:
  - BP
  - ChevronTexaco
  - Colonial Pipeline Company
  - Columbia Gas
  - Domination Transmission
  - Duke Energy
  - El Paso Corporation
  - Enbridge Pipelines
  - Exxon Mobil Corporation
  - Gulf South Pipeline Company
  - Panhandle Energy Company
  - Shell
  - Southern California Gas Company
  - TransCanada Pipeline
  - Williams Gas Pipeline

## Benefits

- The computational tool developed in this project allows the end users to better define the welding process conditions that will result in reduced defects, reduced costs, and energy savings in the fabrication of various components including pipelines.
- Better definition of process conditions will also facilitate the replacement of low strength steels with high strength steels that may be otherwise difficult to weld, resulting in weight, energy, and cost savings.
- Temperatures and times of pre-and post-weld heat treatments can be optimized resulting in energy and consequential cost savings.
- This advanced assessment methodology will lead to safer and more economical operation of existing infrastructures and sound construction and operating practices of new infrastructures in the industries where welding is a key fabrication technology.
- The energy savings are realized through: (1) using less tonnage of steels for the same design and operating conditions, (2) reduction in the amount of welding through the use of high strength steels, (3) reduction in repair welding, and (4) reduction in unnecessary post weld heat treatments.